Bedload Transport. Part 2: The mobile granular Layer

Mickael Pailha, Julien Chauchat, Pascale Aussillous, Marc Médale, Elisabeth Guazzelli

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Mickael Pailha[1] , Julien Chauchat[3], Pascale Aussillous[2],
Marc Médale[2] and Elisabeth Guazzelli[2]

[1] Manchester Center for Nonlinear Dynamics and School of Mathematics, University of Manchester, United Kingdom
[2] IUSTI CNRS UMR 6595 - Aix-Marseille Université (U1), France
[3] LEGI CNRS UMR 5519, Université Joseph Fourier, INPG, Grenoble, France

mickael.pailha@manchester.ac.uk and elisabeth.guazzelli@polytech.univ-mrs.fr

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We present a joint theoretical, numerical, and experimental investigation of the mobile granular layer in bedload transport conditions for pipe flows. The theoretical approach uses a two-phase model having a Newtonian rheology for the fluid phase and Coulomb-type friction for the particulate phase which has been recently proposed by Ouriemi et al. (2009a). This model has been implemented into a 3D numerical code by Chauchat and Médale (2010) which can describe bedload transport in square and circular cross-section ducts. The experiments are undertaken in a rectangular duct partially filled with transparent spherical particles driven by an index-matched fluid. Direct imaging of the particles and of the fluid in a vertical slice is obtained owing to the addition of fluorescing tracers and to the illumination of the duct by a laser sheet. The main quantity that will be examined and discussed is the velocity field.

I Introduction

Recently, a two-phase model describing the bed-load transport in laminar flows have been proposed by Ouriemi et al. (2009a), with a Newtonian rheology for the fluid phase and a frictional rheology for the particulate phase (Forterre and Pouliquen (2008)). This model can be solve analytically away from the threshold of motion and predict a quadratic evolution for the velocity field inside the flowing granular layer. This model gives a quite satisfactory description of indirect experimental observations of bed-load transport in pipe flows Ouriemi et al. (2009a).

In this part we present a direct experimental investigation of the velocity field inside the flowing granular layer in a rectangular duct partially filled with transparent spherical particles driven by an index-matched fluid.

II Experimental setup

The central part of the experimental setup is a rectangular translucent pipe made of glass, 1 m long, 3.5 cm wide and 6.5 cm height as shown in Fig. 1. The pipe is partially filled with a layer of beads and full of fluid. A gear pump generates the flow with a flow rate up to 7 L/min which allows a recirculation of the fluid with a constant differential pressure. A reservoir contains the fluid which is transfered to the pipe with the pump. At the entrance of the pipe, the fluid pass through a porous media made of 1cm glass beads in order to laminarise. The fluid reaches a poiseuille profile on top of the layer of beads and also flows in the layer. Finally it goes back to the reservoir through a sieve to retain the particules which go out.

In order to measure the velocity profile inside the layer, an index matching method is used which make paricles invisible and allows to see through the layer. The optical index of 1.49 is determined by particles made of pmma, 1 and 2 mm with a polydispercity <5%. The fluid, Triton X-100 is choosen as it has the advantage of matching with the particules. The density of

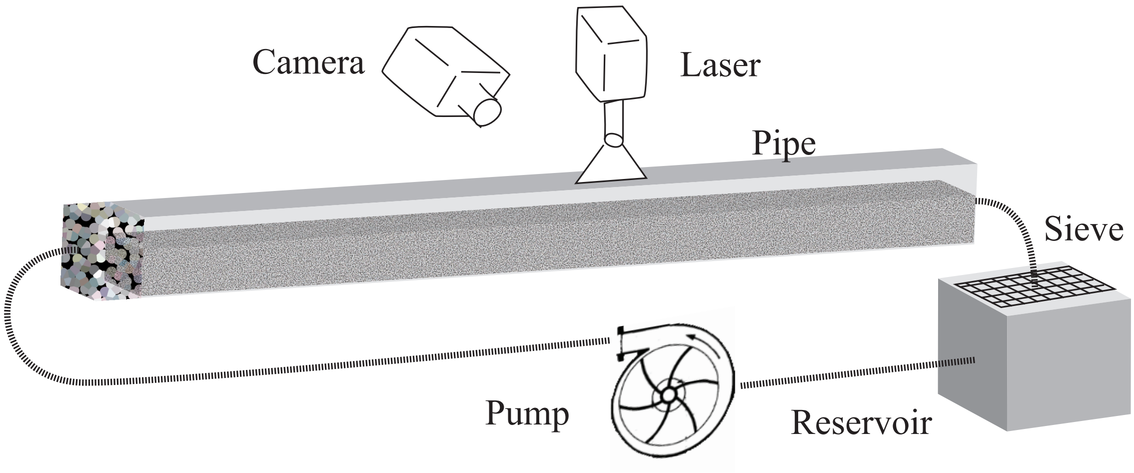

Figure 1: Experimental setup

particles ($1165 kg/m^3$ for 1mm beads $1178 kg/m^3$ for 2mm beads) is closed to the fluid density ($1056 kg/m^3$). So, the particles can easily be transported. The visualison of a transversal section of the flow is possible with a laser sheet from above. Some rhodamine 6g is added to the fluid which fluoresce and the particles appeared in black. The fluid is seeded with tracer particles to visualise the fluid motion.

First, the granular media is initially dilated in order to prevent from crystallization by putting the pipe upside down once and letting the beads sediment. The pipe is tilted to bring back the granular media to the entrance of the pipe. Then a slow flow rate is applied to create a flat interface. Once the fluid area equal to 4 mm, a choosen flow rate is applied. The interface decreases until a height at 7/8 filling where we finally record a movie of the enlightened cross section.

III Experimental results and discussion

From the movie, we can measure the velocity profile and the thickness of the mobile particle layer. Then the the particle flux can be decduced by intergating the velocity profile over the whole layer. Fig. 2 show an image of the central section of the pipe for three flow rates. The velocity profiles are superimposed on the images of the flow and appears in black for the granular phase and in white for the fluid phase. The velocity profile of the granular layer doesn't seem to be quadratic as predicted by the simple two dimensional model. The application of a three dimensional numerical model based on this two-phase approach (Ouriemi et al., 2009a) to this experimental conditions is presented in companion paper Chauchat et al. (2011). The two major quantities that can be measured experimentally and compared with the three dimensional model are the thickness of the mobile particle layer and the particle flux. The comparison between experiments and numerical results will allow to better understand the sediment transport in this peculiar bed-load regime. In particular we would like to confirm the choice of a frictional rheology for the granular phase in this problem.

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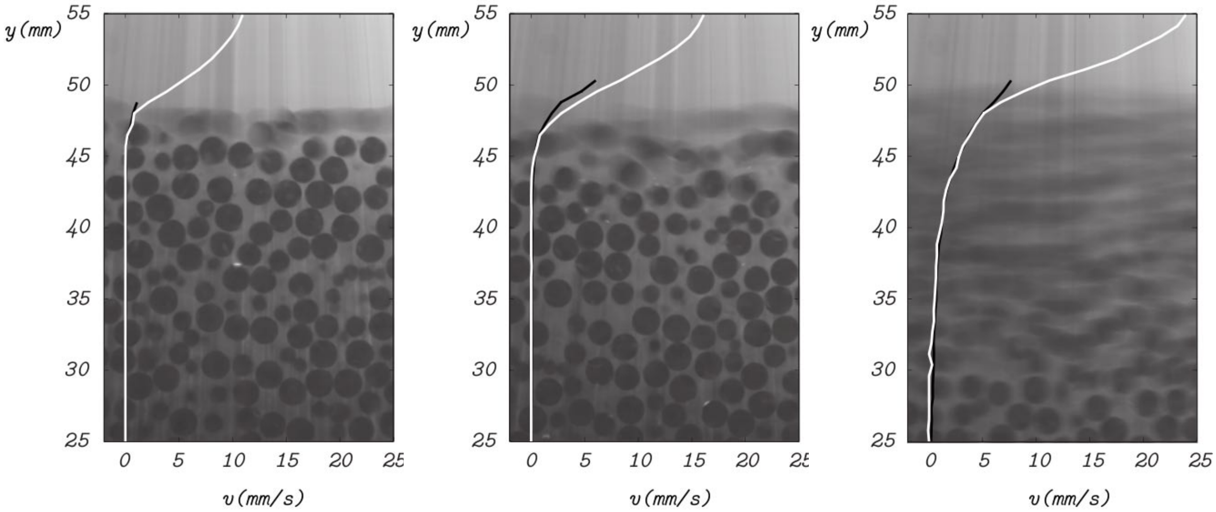

Figure 2: Velocity profile for the granular phase(black) and the fluid phase (white) for PMMA particles, 2mm in diameter in Triton. The fluid flow rate increases from left to right a.$Q = 3.10^{-5}$, b. $Q = 5.10^{-5}$ and c. $Q = 9.10^{-5}\ m3/s$.

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